Floods – Risk and Uncertainty

Introduction

Most people by now have heard of the so-called 100 year flood. The term has come into common use in the news media and some people have had a more direct encounter with the term when they buy or refinance a house in the 100 year floodplain or have to meet floodproofing regulations. Yet, most people have little understanding of how big a 100 year flood is in relation to what might be possible or the residual risk of flooding that remains when a building is "floodproofed' to the 100 year flood level or lies just outside the 100 year floodplain. And when two floods in 20 years exceed the 100 year flood, they assume someone has made a mistake in calculating the 100 year flood. The public also questions how the 100 year flood can change with each new study.

The risk and uncertainty associated with flood magnitudes and frequency is not well understood by many professionals let alone the lay public. Yet, a better understanding of these concepts is essential if we are to make wiser decisions about floodplain occupancy and use, with the end goal of reducing both the public and private burden of flood damages.

Risk and uncertainty are not the same. As applied to floods, "risk" is the probability that one or more floods will exceed a given flood magnitude within a specified period of years. The probability that the 100 year flood will be exceeded at least once in a 30 year period, for instance, is about 0.25 or 25 percent. A house with its lowest floor elevated to the 100 year flood level would then have about a 25 percent risk of sustaining some degree of flood damage over the next 30 years, a typical mortgage period.

Risk can be calculated precisely if the true probability of an event occurring is known. The uncertainty part is that the true probability of a flood event occurring is not known; we can only estimate that probability from what has happened in the past. But the past record of flood peaks - the sample - may or may not be representative of all floods that have occurred or might occur in the future – the parent population. Thus, the estimation of flood frequencies and magnitude always involves some degree of uncertainty. While this uncertainty cannot be eliminated, a relative measure of the uncertainty involved in a flood frequency estimate can be calculated to provide a better understanding of the "looseness" of these estimates.

This paper provides a brief discussion of risk and uncertainty and how these concepts can be used to provide both professionals and the lay public with a better understanding of flood damage potentials.

Risk

There are various approaches to calculating risk but the most understandable and straightforward method uses the binomial distribution. In general, the binomial distribution can be used to determine the chance of an event of known probability "P" occurring or not occurring in "N" tries. Flood frequencies are typically given as the probability of a certain discharge being equaled or exceeded in a given year. Therefore, the binomial distribution can be used to predict the probability that a flood of a certain size with probability "P" will be equaled or exceeded, or not exceeded, in a period of "N" years.

The binomial expression for estimating risk is:

$$R_I = \frac{N!}{I!(N-I)!} P^I (1-P)^{N-I}$$

where R_I is the risk of "I" number of floods occurring in "N" years that exceed a given flood with an annual exceedance probability of "P".

To calculate the risk of non-exceedance, I = 0 and the above equation reduces to:

$$R_0 = (1 - P)^N$$

The risk of one or more exceedances in N years then becomes:

$$R_{\geq 1} = 1 - (1 - P)^N$$

Using this same general approach, the risk of 2 or more, three or more, etc. floods of a certain probability occurring in so many years can also be determined.

The so-called 100 year flood discharge has a one percent probability of being equaled or exceeded in any given year (P = 0.01). Using the above formulas, there is a $(1 – 0.01)^{30}$ or 74 percent chance the 100 year flood will not occur in a 30 year period and, conversely, a 26 percent risk one or more floods in that same period will equal or exceed the 100 year flood. The same approach can be used for different probability floods and different time periods. For instance, the risk of one or more floods exceeding the 25 year flood in a 25 year period is about 64 percent. The risk of one or more floods equaling or exceeding the 100 year flood in a 100 year period is 63 percent, meaning there is a 37 percent chance a flood equal to or larger than the 100 year flood will not occur in the next century.

Risk calculations can be used to provide a better understanding of flood risk as compared to use of terms like the 100 year and 500 year floods. Take for instance the situation where the estimated 100 year flood has been exceeded twice in a 20 year period. The natural tendency is to assume that the 100 year flood estimate is wrong. Using risk principles, however, there is about a two percent chance that two or more floods exceeding the 100 year flood can occur in a twenty year period. While this would be a relatively rare occurrence, it certainly is within the realm of possibility and the 100 year flood estimate may not be wrong. Another situation might be where there is 100 years of flood record at a particular location but the estimated 100 year flood as used for a floodplain study is somewhat larger than the largest flood that has occurred in the past century at this site. There is about a 37 percent chance a flood equal to or larger than the 100 year flood has not actually occurred in the last 100 years. In other words, any floodplain occupants at this location have been somewhat lucky in that they have not experienced a 100 year or larger flood in the last century.

The 100 year flood is all too often (and incorrectly) considered a benchmark as to whether a property or building is floodprone or "floodproofed". A new house that has been built in the floodplain likely has its lowest floor elevated to the 100 year flood level to meet floodplain development standards. A real estate agent likely will say the building is "floodproofed" and the buyer likely will not purchase a flood insurance policy unless required to do so. Yet, this house would have about a one-in-four chance of being flooded within the next 30 years and a regular home insurance policy would not cover any flood losses. If presented with the "one-in-four" risk scenario instead of the "floodproofed" assertion, the prospective buyer might opt to buy a house on higher ground or, at a minimum, purchase a flood insurance policy. Similarly, a house lying just outside the 100 year floodplain might be considered to not be floodprone when in fact its flood risk is still significant – about the same as a house with its lowest floor elevated to the 100 year flood level. Very few people purchase flood insurance for buildings lying outside the mapped 100 year floodplain as those buildings are typically considered "not in the floodplain".

Water treatment plants might be considered critical facilities as many other functions such as hospitals and fire fighting depend on the availability of water to carry out their responsibilities. These functions are especially critical during times of emergencies. Iowa's floodplain management regulations require that water treatment plants be protected to a level one foot above the 100 year flood level. Unfortunately, this minimum level of protection all too often becomes a de facto design standard. Design professionals seldom look beyond the 100 year flood requirement. A more holistic look at flood risk might suggest that a much higher level of protection is warranted. If, for instance, the design professional realized there was about a one-in-five chance a plant protected to the 100 year flood level would be flooded in an expected 25 year design life, he or she might provide a much higher level of protection considering the critical nature of keeping the water plant running at all times.

Risk concepts can also be used to estimate average annual flood damages. In general, a damage-probability curve is generated from flood frequency and height data and stage-damage relationships for a particular type of structure. In terms of average annual damages versus annualized construction costs, the cost of incorporating additional flood protection (and lowering the flood risk) into a structure may be a fiscally wise move.

Below is a table of the risk that a flood of a certain probability will be equaled or exceeded at least once in a given number of years. More detailed information can be found in Appendix 10 of Bulletin 17B, Guidelines for Determining Flood Flow Frequency, of the Interagency Committee on Water Data.

Risk of one or more floods equaling or exceeding a flood of probability "P" or recurrence interval "RI" in a period of "N" years

P/RI(yrs)	Time period "N" – number of years					
	10	**30**	**50**	**70**	**100**	**200**
0.10 / 10	65	96	99	≅100	≅100	≅100
0.04 / 25	34	71	87	94	98	≅100
0.02 / 50	18	45	64	76	87	98
0.01 / 100	10	26	39	51	63	87
0.002 / 500	2	6	10	13	18	33

Uncertainty

There are various approaches to developing flood frequency relationships but all include a degree of uncertainty in trying to predict the frequency and magnitude of future floods based on what has happened in the past. As the record of past events is often relatively short, estimating the magnitude of relatively rare events is a challenge and often involves a significant degree of uncertainty. Yet, it's something that is done routinely for flood studies with the notion the results are relatively accurate.

As an example of uncertainty, consider the probability of getting, or not getting, a full house or better hand in a game of five card stud poker. There a known number of cards of each kind in a deck and only so many combinations of five will yield a full house or better hand, so the exact probability of drawing a full house or better in one hand can be mathematically determined – it's 0.0017. Over the long term – thousands and thousands of hands - about one hand in every 589 hands of five cards will be a full house or better hand.

Assume, however, that a poker player doesn't know the exact odds but wants to get a better "seat of the pants" feel for the odds of being dealt a full house or better. He proceeds to randomly deal out 100 five-card poker hands and counts the number of hands that are full houses or better and finds that one of the hands are such hands. He might then assume his chance of drawing a full house or better in a given hand of five card stud is 1/100 or 0.01. This of course is considerably different than the true probability of 0.0017.

Using the above risk equations, it can be determined that there is a about ~~a~~ 14 percent chance that one hand out of 100 will be a full house or better. This poker player was "lucky" as he beat the odds; 86 percent of the time there would not be a full house or better in 100 hands. And, as a result, he has a distorted picture of the true probability of getting a full house or better hand. Due to the relatively small size of the sample – 100 hands – and the relative rarity of the event – a full house or better – there is a large degree of uncertainty in this empirical approach. If he would have dealt himself 1000 hands instead of 100, he would have increased the sample size and reduced, but certainly not eliminated, the uncertainty.

Predicting flood frequencies and magnitudes are a lot like the poker example. The true probabilities are not known and never will be. Instead, an empirical approach is taken where the probability estimates of future flood events are based on what has happened in the past. The problem is there aren't thousands of years of record to analyze. The estimated magnitudes of relatively rare events like the 0.01 and 0.002 exceedance probability floods (the 100 and 500 year recurrence interval floods) are often based on a statistical analysis of 50 years or less of flow records. Even at the few sites where there are around 100 years of record, accurately estimating the magnitude of the 100 year flood is a challenge. You cannot say the largest flood in those 100 years is the 0.01 exceedance probability flood as there is a 37 percent chance the 100 year or larger flood has not occurred in that 100 year period. On the flip side, there is a 26 percent chance that two or more floods in those 100 years exceeded the 100 year flood. There's also an 18 percent chance the 500 year or larger flood occurred. Thus the uncertainty as to what the "true" 0.01 probability flood – the 100 year recurrence interval flood – really is.

Hydrologists have over the years attempted to reduce the uncertainty of flood estimates by various statistical techniques. The current recommended method for determining flood frequencies and magnitudes for sites where there are continuous record gaging stations is the log-Pearson Type III method. This approach is fully explained in Bulletin 17B and while this is currently considered the de facto standard, Bulletin 17B estimates can still have a significant degree of uncertainty. Appendix 9 of Bulletin 17B contains equations for calculating confidence limits for 17B-derived flood estimates and these confidence limits can provide a measure of the uncertainty associated with a flood frequency estimate. For example, the log-Pearson analysis of 50 years of flow records might result in a 100 year flood peak flow estimate of 50,000 cfs. If the associated upper and lower 95 percent confidence limits were 69,000 and 38,000 cfs, respectively, then it could be said we are about 90 percent certain that the "true" 100 year flood peak is somewhere between 38,000 and 72,000 cfs.

The Cedar River at Cedar Rapids provides a good example of uncertainty. There has been a gaging station in downtown Cedar River in continuous operation since 1903, providing 106 years of annual flow peaks. Using Bulletin 17B techniques and including the very large 2008 flood peak, the estimated 100 year flood peak is about 90,000 cfs. The associated upper and lower 95% confidence limits are 110,000 and 76,000 cfs, respectively, meaning there is about a 90 percent certainty the true 100 year peak discharge for this site is somewhere between 76,000 and 110,000 cfs. Using the stage-discharge relationship for this site, this 90 percent confidence band translates into a vertical difference of around five feet. The Cedar River at Cedar Rapids is about as good at it gets in term of flood records but even at that the true 100 year flood elevation can only be estimated within a five foot range with 90 percent certainty.

There is also uncertainty involved in estimating flood levels associated with a particular peak discharge, especially when there are no historic flood profiles or high water marks to calibrate a water surface profile. Another uncertainty of some concern is whether climate change is altering longer-term precipitation patterns. If longer-term trends are taking place, the past record may be of limited value in predicting future flooding. These additional uncertainties only add to the uncertainty inherent in calculating flood frequency relationships.

Unfortunately, few flood studies contain any discussion of the uncertainties associated with flood estimates. Published flood discharges are not even qualified as being a "best estimate", subject to a certain amount of uncertainty. If a city council understood this uncertainty, they might elect to require a higher level of protection for flood plain development - a "let's error on the conservative side" approach. Published confidence levels might provide the legal and political ammunition to justify such a higher level of protection.